Ceiling Construction to Counter Effects of Truss Uplift

Report No. ____________

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Ceiling Construction to Counter Effects of Truss Uplift

Prepared for: The Technical Research Division Policy Development and Research Sector of Canada Mortgage and Housing Corporation

by

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FOREWORD

For the person who is unfortunate enough to own a house which suffers damage caused by truss uplift, the problem is a very real one. The repetitious cracking of the wall/ceiling drywall joint is difficult to remedy. It is small consolation to be informed that the problem only occurs infrequently, and then usually only to a degree which causes minor damage.

The problem is certainly serious enough however to warrant research into how it may be alleviated, especially since trends in lumber sources and use of abundant insulation in attics will exacerbate the situation. Though methods could be devised which would prevent its occurrence, there would in practice be many difficulties with this approach. The more fruitful course appears therefore to construct in such a manner as to accommodate the phenomenom. This project has involved the flexing of drywall panels and joints to destruction, and therefrom deduced practices which allow for relative movement between trusses and partition walls without resultant damage.

The reader should be cautioned that the report's conclusions being based on tests under laboratory conditions, must be treated with some degree of caution until the suggested practices have been verified by field testing.

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EXECUTIVE SUMMARY

The purpose of this study was to recommend changes in the manner of attaching gypsum board ceilings to roof trusses and partitions to obviate tearing of joints caused by truss uplift.

Both specimen testing and full-sized joint testing were undertaken. The specimen tests involved testing gypsum board as cantilevers to assess their flexibility and their flexural resistance. Flexural tests conforming to the CSA Standard for physical testing of gypsum board were also done. Using the information from the above tests, an attempt was made to design for a truss/partition separation of 15 mm which would provide sufficient flexibility to handle most occurrences of truss uplift.

Four full-sized T joints were built and tested. Two joint specimens simulated partitions located perpendicular to the trusses and two simulated partitions parallel to the trusses.

Quite adequate joint performance was observed at the design separation but for the development of small hairline cracks at the root of each joint. Repeated cycling of the separation did not cause any further apparent change in the behavior of the joints. Separation to failure showed that quite a large reserve was available before bending failures occurred in the ceiling gypsum board.

On the basis of these tests and calculations for 1/2-inch (12.7 mm) gypsum board ceilings, a minimum nailing setback of 460 mm (about 18 inches) is recommended when partitions are perpendicular to the trusses and 400 mm (16 inches) when they are parallel to the trusses. A setback of 200 mm (about 8 inches) from the corner is recommended in the attachment of gypsum board on the walls in conformance with industry recommendations to minimize peeling of the paper tape or face paper at the joint. Metal framing clips at 610 mm centers were used to pull the ceiling gypsum board down with the partition. Wood blocks would also probably serve if securely attached to the top of the wall. It is also recommended that trusses not be supplied with excessive camber because they create problems for the builders when installing ceilings. The practice of nailing down trusses to partitions to facilitate ceiling installation may aggravate the possibility of the top plate or plates being pulled from the wall or of lifting of the entire wall away from the floor.

TABLE OF CONTENTS

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by

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1.0 INTRODUCTION

Truss uplift continues to be a problem for builders. In Canada, Plewes (1) first articulated possible causes of the problem and made estimates of uplift which might occur for a given set of conditions. These compared favorably with uplift found in two different case studies, one involving bowstring trusses in a mobile home and the other, Howe trusses in a single family residence. Percival and Comus (2) have recently reported on current research on the problem at various institutions and suggested possible solutions. Some of the efforts underway are of an experimental nature to demonstrate that truss uplift occurs when environmental conditions for top and bottom chords are different. Other work is associated with field inspection of houses having this problem and of attempts to correlate various factors with the fact that uplift was occuring. The field studies have generally been inconclusive but have identified that most of the cases studied could be attributed to "arching" of the roof trusses, as opposed to settling of foundations.

The Eastern Forest Products Laboratory (EFPL) has been monitoring the moisture content and deflection of trusses in the HUDAC research house, designated as the Mark XII project (3). In this study, it was found that the bottom chord dried out to a relatively low moisture content and did not vary much over the period of observations. The top chord on the other hand, picked up moisture from the air in the winter and dried out in the summer. This corresponded to the rise and fall of the ceiling.

In an assessment of the truss uplift problem and possible solutions, Onysko (4) pointed out two practical solutions which some builders were using to float the ceiling and prevent separation from being apparent in new housing. These were:

a) Attachment of the gypsum board ceiling to the bottom chords of the trusses but not nailing within 18 inches of any interior partition. The edges of gypsum board ceilings within the room are held by clips to the interior partitions. If the trusses deflect upward, the gypsum board ceiling flexes and does not separate from the interior partitions. Some builders have referred to this solution as "floating the corners" of ceilings.

b) A variation on this solution includes the use of 1 x 3 wood strapping which is nailed to the bottom chords of the trusses and which is allowed to flex between some point of attachment to the truss and the wall where the straps are securely attached. In this case, the gypsum board is nailed to the wood straps as needed in the normal way. Although this requires the use of more material, the use of strapping provides a smoother finished ceiling because the strapping makes up for slight differences in elevation between trusses. Some builders prefer this technique for ceilings for this reason.

At a meeting of the Task Group on Truss Uplift of the HUDAC/TRC on May 1, 1980 in Toronto the first solution noted above was identified as one of the simplest and least costly to implement.

With the above as background, Canada Mortgage and Housing Corporation (CMHC) commissioned Forintek Canada Corp to undertake a small study to recommend nail or screw spacings necessary to permit the edges of a ceiling to "float" and handle the majority of occurrences of truss uplift. The following is a report on the studies undertaken.

2.0 OBJECTIVES

The objectives of this study are to investigate and advise on suitable practices of fastening gypsum board to ceilings to accommodate the relative movement between partition walls and truss mounted ceilings.

3.0 EXPERIMENTAL APPROACH

The strength and stiffness of the gypsum board were obtained from bending of two specimen types. This information provided the basis for calculation of the necessary distance between the closest fastener location and the face of the partition framing. These calculations assumed that a design separation of 15 mm (0.59 inch) was required. Full scale specimens were then built and tested to assess whether the approach was successful and to determine what reserve capacity there was for additional separation.

4.0 MATERIALS

Six sheets each of 1/2-inch gypsum board (05050H43) and 5/8-inch Fire Code 60 gypsum board (05210H46) produced by Canadian Gypsum Company Ltd. were purchased for the tests. They were numbered, cut in half, and conditioned in a laboratory at a temperature of 20°C and 50 percent relative humidity in conformance to CSA Standard A82.20-3-M77 "Methods of Testing Gypsum and

Gypsum Products". Constant weight was achieved within 7 days and before tests were begun.

No. 1 Grade 2 x 4 Spruce-Pine-Fir framing was used for the full scale tests and it had achieved "dry use" conditions (12 percent MC) on being stored in the laboratory for a long time under similar conditions.

Light gauge gypsum board corner framing clips were supplied by K. Sexton of Kenroc Building Materials Ltd. in Regina. These are presently only available for use with 1/2-inch gypsum board. The bottom lugs were removed to permit the clips to be used with 5/8-inch gypsum board. In practice, the bottom lugs are required for holding and erection purposes but were not necessary in this work because the gypsum board specimens were tested upside down.

5.0 PROCEDURES

5.1 Cantilever Bending Tests

Two sheets of each thickness of gypsum board were cut into approximately 2-foot by 4-foot specimens in accordance with the cutting pattern shown in Figure 1. Half the specimens were aligned with the sheet direction and half were aligned perpendicular to the sheet direction. Each specimen was then tested in bending as a cantilever as shown in Figure 2. The distance from the free end (where the force was applied by pulling on the framing clip) and the first nail attaching the specimen to a piece of 2 x 4 lumber (simulating the bottom chord of a roof truss) was varied from one specimen to another. The matrix of cantilever distances used is given in Table 1.

With the 2 x 4 lumber piece anchored to the base of a testing machine, the free end of the specimen was raised at a constant displacement rate of 5 mm per minute until failure occurred. The load was applied through a framing clip nailed to a 2 x 4 which was bolted to a swivel mounted to the moving head of the testing machine. The duration of test to failure varied from 6 to 33 minutes, the time required varying with the cantilever span. A different clip was used for each test.

The strength and deformation of gypsum board is time dependent. Each cantilever distance involved a different rate of strain at the critical section. The slow rate was chosen in an attempt to minimize the differences from one specimen to another. This specimen type was chosen because it simulated both the nail pull-through test, the bending test and also tested the ability of the cut edge to take load imposed by the framing clip. A summary of the test results is given in Tables 2 and 3.

5.2 Standard Bending Tests

The CSA A82.20-3-M77 bending test involves breaking a 16 x 12 inch (400 x 300 mm) specimen in bending face down on a 14-inch span at a rate of 5N/sec. A variable number of specimens of this size were cut from portions of the cantilever specimens remaining from the cantilever bending tests. As each specimen had a different stiffness and a constant rate-of-loading testing machine was not available, the rate of displacement was varied to achieve a rate of load application that fell within the limits of the specification (± 10 percent) to the point at which failure began. The test results for these bending tests are summarized in Table 4.

5.3 Full Scale Tests - Fabrication

The fabrication details of 4 full-sized T specimens, two for each gypsum board thickness, are given in Figures 3 and 4. One T specimen of each thickness simulated a partition crossing the trusses at right angles, and the other simulated a partition lying parallel to the roof trusses. The distance from the edge of the partition to the first row of nails was different on each side of the partition. The distances chosen represent a range within which it was thought the final recommendation would be found that would permit the required separation to take place without distress to the joint.

The T specimens were constructed with the 2-foot high stub wall braced to the horizontal portion. Just prior to test, the bracing was removed so that only the gypsum board held the stub wall in place. The gypsum board framing clips, at 24-inch centres, were nailed to the wall plate and they held the edge of the ceiling gypsum board in position. These clips are designed to grip the full thickness of 1/2-inch gypsum board. When they are required to hold the tapered edge of 1/2-inch gypsum board the fit is loose. In this case it is necessary to tap the bottom lugs to close the gap, otherwise the plaster and tape will have to carry the strain instead of the framing anchor, at least until some separation and failure of the joint had occurred.

The joints were prepared with premixed joint filler and paper tape in a three stage operation as outlined in the Residential Standards (5). The jointing was done by a technician who practised on dummy joints until he became proficient at the task and was able to produce a quality of joint that was not dissimilar to what one might expect of good field practise.

5.4 Full Scale Tests - Procedure

The stub wall on all full size joint specimens was separated from the ceiling framing assembly as shown in Figure 5. The rate of separation was 5 mm/min until an average design separation of 15 mm was achieved. The force required to achieve separation and the separation on each side of the specimen were monitored. This separation was held for 24 hours. The appearance of the joints on both sides was monitored during separation and at the end of the 24-hour hold period.

The two specimens (1/2-inch and 5/8-inch gypsum board) that simulated a wall perpendicular to the trusses were subjected to 10 cycles of separation from 0 to 15 mm, with separation taking 5 minutes followed by a 5 minute hold period at 15 mm separation and a return time of 5 minutes.

The final test on each full-sized joint was a separation to failure at a rate of 5 mm/min. Load and separation readings were taken to the limit of the range of the dial gauges used. Separation was continued until a failure or major loss in resistance occurred.

6.0 RESULTS

6.1 Cantilever and Standard Bending Tests

The results of the cantilever tests are given in Tables 2 and 3 while the results for the standard bending test are given in Tables 4 and 5. Comparison of these tables shows that the bending stiffness determined from the cantilever bending tests is lower than that determined from standard bending tests. Further, the apparent bending stiffness from the cantilever bending test is strongly dependent on the cantilever distance. There are several reasons for this.

a) Flexibility in the clip leads to greater apparent deflections and a lower apparent EI product. Short cantilevers require a higher force to cause a given displacement and one should expect lower EI products for these specimens than for those with longer cantilever distances.

b) The point of fixity for each cantilever is not constant. Deformation in the region of the resisting nails permits more displacement at the cantilever tip and results in a lower EI product. Shorter cantilevers will be subject to greater error in the apparent EI product than longer cantilevers.

c) The calculation of bending stiffness is made using beam formulae where it is assumed that load application is applied uniformly across the width of the specimen. In these tests, loads are applied at localized regions both through the clip and at the resisting nails. Localized bending leads to a lower EI product.

d) The maximum rate of strain was different for each cantilever distance and thickness. Since the apparent modulus shows time dependent behaviour, one should expect lower EI products with increasing cantilever span. The fact that the reverse was found implies that if the maximum rate of strain at the point of fixity had been held constant for all tests, the differences in EI product would have been even larger from one span to another than is reported here.

With all of these factors apparently working against the obtaining of data that can be relied upon one might conclude that the cantilever tests are not useful. However, contrary to this conclusion one can say that in practice, as in the cantilever test, it is advantageous for the apparent EI product to be lower than it actually is, especially for short cantilever distances. This is because the joints will have greater ability to absorb a given degree of separation without breaking the gypsum board or pull-through of the nail heads than would be calculated based on an EI product that is closer to the truth. The cantilever test serves to show the degree to which separation over and above that based on the properties of the gypsum board alone can be absorbed. For 1/2-inch (12.6 mm) gypsum board the ratio of the EI calculated from the cantilever test to that calculated for the standard bending test ranged from 0.41 to 0.92 while for 5/8-inch (15.9 mm) gypsum board this ratio ranged from 0.43 to 0.83. The greatest discrepancy was for the shortest spans while the least discrepancy was for the longest spans.

6.2 Full Scale Joint Tests

6.2.1 Initial Load Application to 15mm Design Separation

The condition of the joints during separation and after the 24 hour hold period was very good. Very small hairline cracks usually appeared at the root of the joint. These cracks were short in some cases and full length in others and were caused by rotation of the ceiling gypsum board relative to that on the wall. The cracks were too small to measure with fine wire loops. It is believed that they would not be noticable in the normal course of events.

Plots of load versus displacement are given in Figures 6 and 7. They are all similar in appearance. The relative positions of the curves do not have much meaning. The load required to cause separation in each case was dependant on the resistance of two unequal cantilevers. From the secondary slopes the effective EI product can be calculated. These were found to be an average of 320,000 and 274,000 Nmm^2/mm for the 1/2-inch gypsum board and 633,000 and 671,000 $N\,mm^2/mm$ for the 5/8-inch gypsum board, for the stiffest and least stiff principal directions respectively.

These values lie between or above the EI product values obtained from the cantilever bending test and the standard bending test. The main differences between the cantilever tests and the full scale tests are that the force causing separation is partly distributed by the plaster joints and some rotational fixity is provided at the free edge by the plaster joint.

6.2.2 Cycling of a 15mm Separation

Only two T specimens were cycled, both simulated the partition-perpendicular-to-trusses case. Very little change in joint performance was noted. Hairline cracks that might only have been partial length propagated full length after the first few cycles. The load required to cause separation of this magnitude remained constant. Aside from the full-length propagation of hairline cracks, no distress was noted.

6.2.3 Separation to Failure

Plots of load versus average separation are given in Figures 8 and 9. In all cases failure, as defined by a significant loss in load, was caused by tensile failure of the back face of the shorter of the two cantilever spans. While some depression of nail heads into the top faces was observed, no nail pull-through failures occurred.

Again, the relative positions of the curves depends on the cantilever distances involved and the weight of the stub wall. Considering first Figure 8, with the partition perpendicular to the trusses (or parallel to the sheet axes as normally applied to ceilings) the curves are similar for both 1/2-inch and 5/8-inch gypsum board. The first major change in curvature at about 20mm separation for the 1/2-inch gypsum board and 30mm separation for the 5/8-inch gypsum board resulted because the joint tape started to peel. Although peeling began, it was not visible from a frontal view but only by examining the edges of the joints.

No disruption at the joint was visible externally, even when the 400mm cantilever failed in bending. Peeling occurred because the cantilever tip moved away from the wall as well as upward. The gypsum board on the wall could not follow suit. While some tearing of the joint paper of the 5/8-inch gypsum board specimen occurred, this could have been repaired after closure of the separation.

In the case of Figure 9, for two specimens simulating partitions parallel to the trusses, peeling of the joint paper began at about 27mm separation for the 5/8-in. gypsum board and about 20mm separation for the 1/2-inch gypsum board. Peeling was more noticeable on the shorter cantilever spans of all specimens because movement of the cantilever tip had a larger horizontal component. Peeling of the joint paper progressed on separation, continued until the joint paper separated from the wall, or, where bond was very good, peeling included the face paper on the wall and propagated up it. This only happened on the short cantilever side of each specimen. No disruption was apparent externally on the longer cantilever side even when the shorter cantilever failed.

In all cases, the clips performed well and were not a factor in limiting performance of the full-sized joints. Peeling was related to the cantilever span. It was more a function of geometry than of strength of the bond, a larger separation being tolerable for longer cantilever distances. There did not appear to be any peeling at the design separation of 15mm. Only at a separation of about 20mm for the 400mm cantilever was there a noticeable effect on the force required to cause separation.

7.0 DISCUSSION

Using data generated by the cantilever bending test and the standard bending test, an attempt was made to "design" for a given truss-partition separation. There is insufficient data available to enable one to be able to know what percentage of cases would be handled by any particular design separation. The design separation selected for this study (15mm) was thought to be sufficient to handle the majority of cases. Depending on the minimum cantilever distance used, there can be substantial reserve to absorb larger displacements without very much apparent distress except for some of the extremely rare cases where from 40 to 70mm are reported. While these too can be designed for, long cantilever distances are required. Too long an unsupported span of gypsum board will lead to sag with time under its own weight and the weight of insulation it must also carry. In this instance, the gypsum board should be attached to a separate strapping system. Nailing of the strapping to the trusses could be held 1 to 1.5 meters from the interior partition walls to provide sufficient flexibility.

The material properties obtained in this short study are very meagre indeed. For this reason, the tentative recommendations made in the following section should be treated with some degree of caution. A data base of properties for different brands of commercial gypsum boards is needed to provide a basis for firm recommendations. The required data base should provide informaton on both mean values and distributions for the following properties; bending stiffness about both principal axes, bending strength about both principal axes both with the face paper in tension and the back paper in tension, and the nail and screw pull-through resistance. Finally the peeling properties of joints as influenced by the width of the paper tape and its strength and the manner of joint fabrication should be studied. The performance of the full-sized joints demonstrated that the design separation could be met readily. The calculation of the deformation performance of full-sized joints can be done and a given factor of safety against nail pull-through or tension failure can be provided on the basis of short term test information.

Long term performance is influenced by moisture cycling, moisture content and lonq term loading. We are not aware of studies in the public domain on this topic. Although no distress was observed from cycling, it is possible that repeated cycling from one equilibrum position to another may eventually lead to fatigue if the separation is large.

Finally, while the design separation was attained in several minutes, in práctice it will be attained in from two weeks to over a month. The effect of different rates of strain in testing gypsum board is not known to the authors. This study did not provide opportunity for a search of the literature. It is suspected that much of the work on time dependent behaviour under load of paper and even wood may assist in explaining the performance of gypsum board.

8.0 CONCLUSIONS

The experimental work presented in this report are of very limited nature. The computations in Appendix A showed how fragmentary the short term data was and how many assumptions were required to extrapolate short term tests to the situation current in a truss roof undergoing uplift. Industry data on the average properties and their distributions were not available to this study but are necessary to assist in drawing firm conclusions. Some industry data, especially the nail pull-through information from CSA A82.20.3M77 testing, will not be too useful because the manner of preparation of the test specimen does not duplicate the severity of surface damage which can occur during nailing. Again, the gypsum board industry may have other data on the subject which may be of use.

The few experiments done showed that large separations can be accomodated. The primary goal of the tests and calculations was to recommend minimum nailing distances from the partitions to avoid premature bending failure or nail pull-through. No testing or reports were available to us which would be of assistance in assessing the maximum nailing distance that could be permitted. These distances would more likely be controlled by sag of the gypsum board.

Gypsum board has non-linear properties that are strongly influenced by moisture and time under load. It is suspected that there is not very much research on gypsum board in the public domain because the behavior is th ht to be theoretically intractable and not predi e in practice. The approach we took in Appendix A was listic but probably conservative. We hesitate to say t all the assumptions are supportable.

Considering recent problems in the field with sag of gypsum board with supports at typical spacings, extending the spans beyond these typical spacings should not be considered. The risk of obtaining unacceptable sag is too high not because the gypsum board is not necessarily up to the task but because the conditions to which it is subjected are uncontrolled.

Given the recommendations in the following section, full-scale joint testing in which dead loading, cycling of moisture conditions alternatively with separation to a design value should also be investigated.

9.0 RECOMMENDATIONS

Insufficient nail pull-through test data was available to permit us to compute possible minimum nailing distances for 5/8-inch gypsum board. Minimum nailing distances are advanced for 1/2-inch gypsum board ceilings only.

(1) The minimum nailing distance recommended when partitions are perpendicular to the trusses is 460 mm (about 18 inches) from the face of the partition.

(2) The minimum nailing distance recommended when partitions are parallel to the trusses is 400 mm (about 16 inches) from the face of the partition.

(3) When partitions are parallel to trusses care must be taken to adequately support the gypsum board so that sagging is not a problem.

(4) Interior partitions should only be fastened to trusses as required to stabilize the structure during construction. The connection should be made to allow nails to pull out if uplift takes place. If trusses are too securely nailed to the interior walls they may pull the top plate from the wall or as has been observed, they may lift the whole partition away from the floor on which it stands. It almost goes without saying that trusses should not be supplied to the site with excessive camber built in. Builders tend to try to take some of this camber out during construction by nailing them to the partitions. Subsequent truss uplift, produced as a result of differential shrinkage of truss chords, may then cause these connections to release and doubly

aggravate the apparent separation. Builders must be certain that trusses are well fastened to the supporting walls since the weight of interior walls can not now be counted on to assist a roof to resist uplift caused by high winds.

(5) Galvanized steel framing clips or wooden blocks are required to hold the ceiling to the top of the partition. Nailing of these hold-downs to the partitions should be secure. If wooden blocks are used they should be securely attached with at least two 3-inch or 3-1/2-inch nails. The maximum spacing of hold down was not investigated. Framing clips at a 610 mm spacing were found to be quite adequate.

(6) In these tests, the wall gypsum board was nailed to the top plate of the partition. At larger separations it was noted that the cantilever tip deflected horizontally and pulled on the edge of the gypsum board attached to the stub wall. This hastened peeling of tape. Had the nailing been done entirely in accordance with recommendations by the gypsum board manufacturers, which entails a nailing set back of 8 inches (203 mm) at the top of the wall, this would not have occurred. The industry recommendation on this matter is endorsed

by the authors.

Finally, some of the practices recommended in this report do not fully conform with either the Residential Standards of Canada or with those recommended by the gypsum board industry. It is recommended that these practices be considered for general use upon due deliberation and possible additional testing by the gypsum board industry and others interested in maintaining sound residential construction.

10.0 REFERENCES CITED

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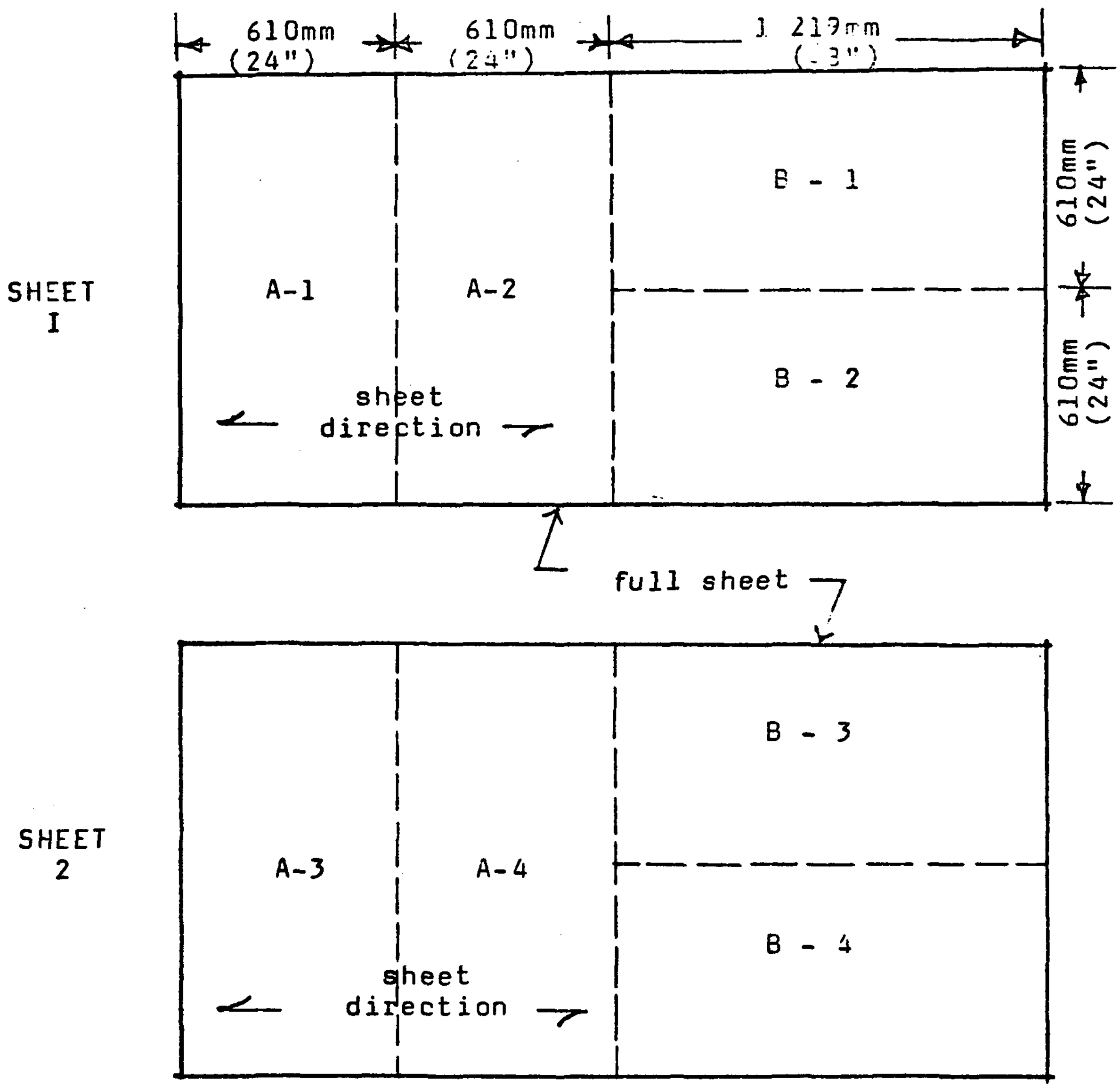


FIGURE I: Cantilever tests - specimen layout and labelling

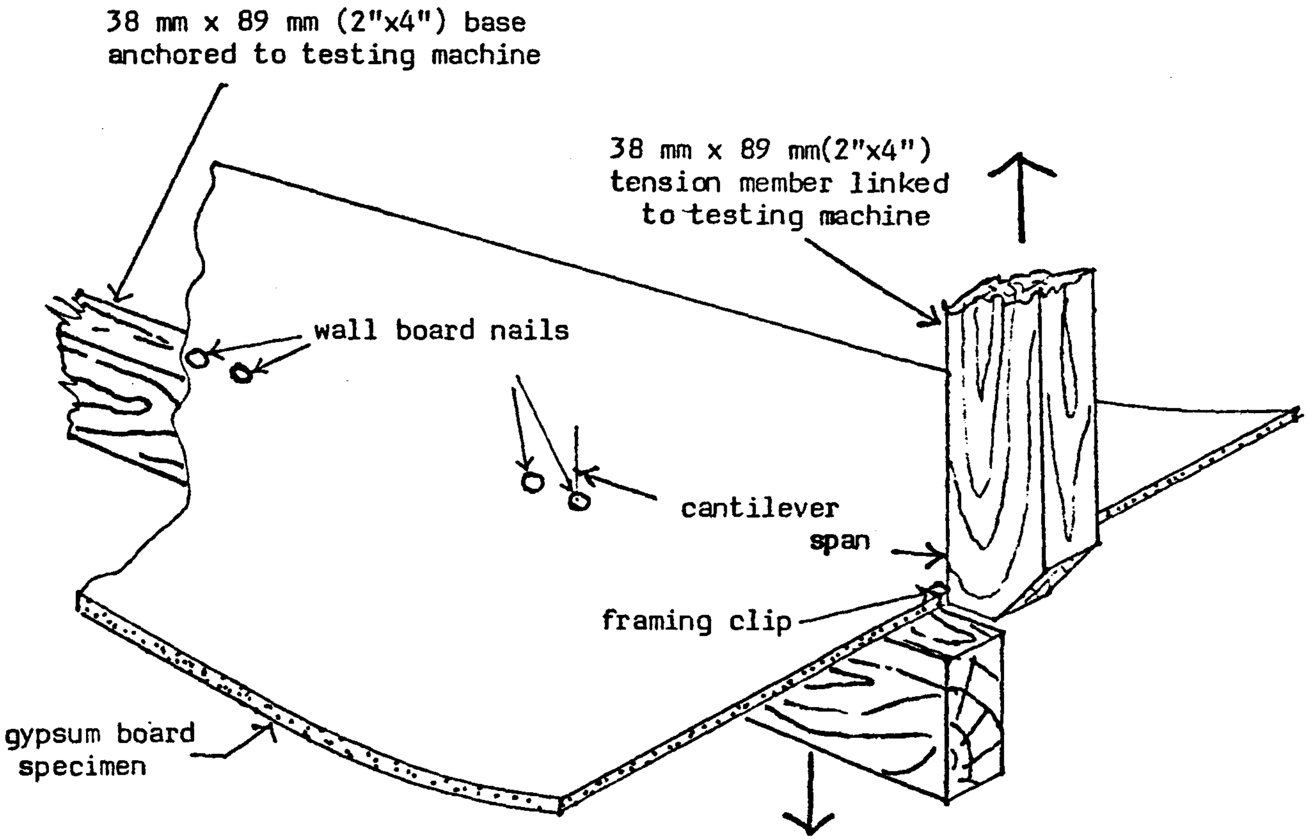
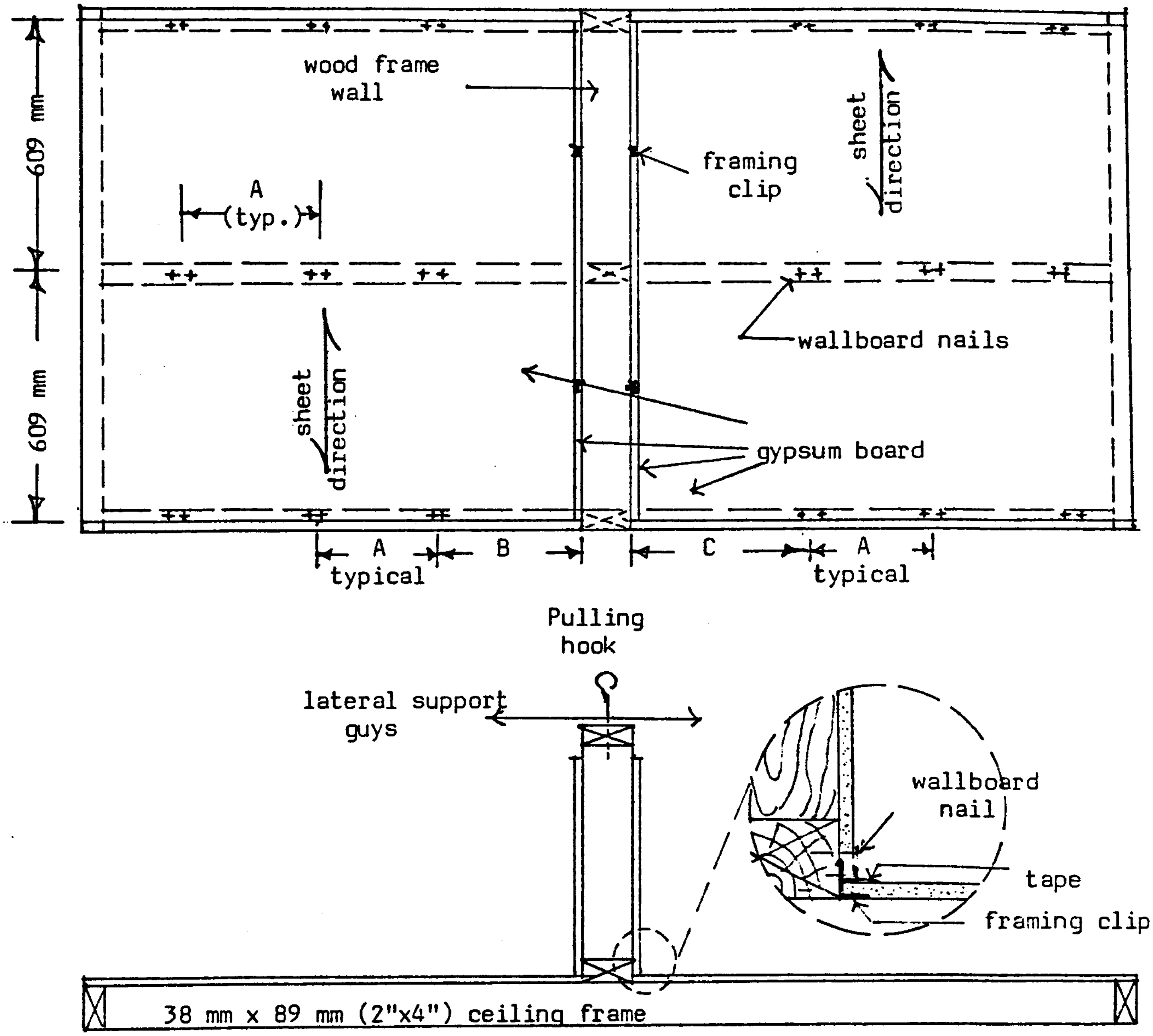
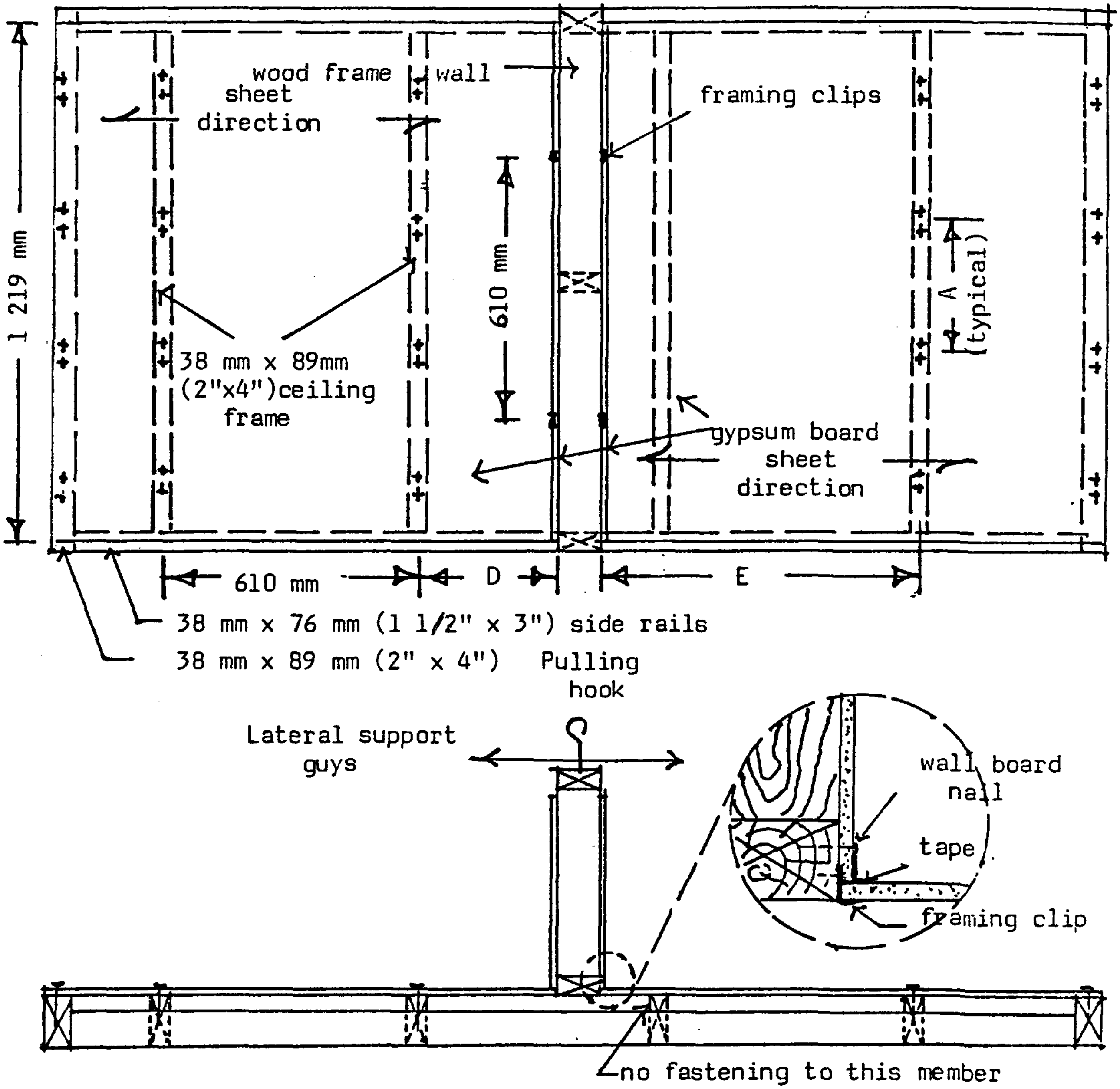


FIGURE 2: Set up for the cantilever bending tests.



Gypsum board thickness	A	B	C
12.7 mm	300 mm	400 mm	600 mm
15.9 mm	300 mm	600 mm	800 mm

FIGURE 3 : Full-sized T-specimen simulating a partition perpendicular to roof trusses



Gypsum board thickness	A	D	E
12.7 mm	300 mm	400 mm	700 mm
15.9 mm	300 mm	500 mm	900 mm

FIGURE 4: Full-sized T-specimen simulating a partition parallel to roof trusses.

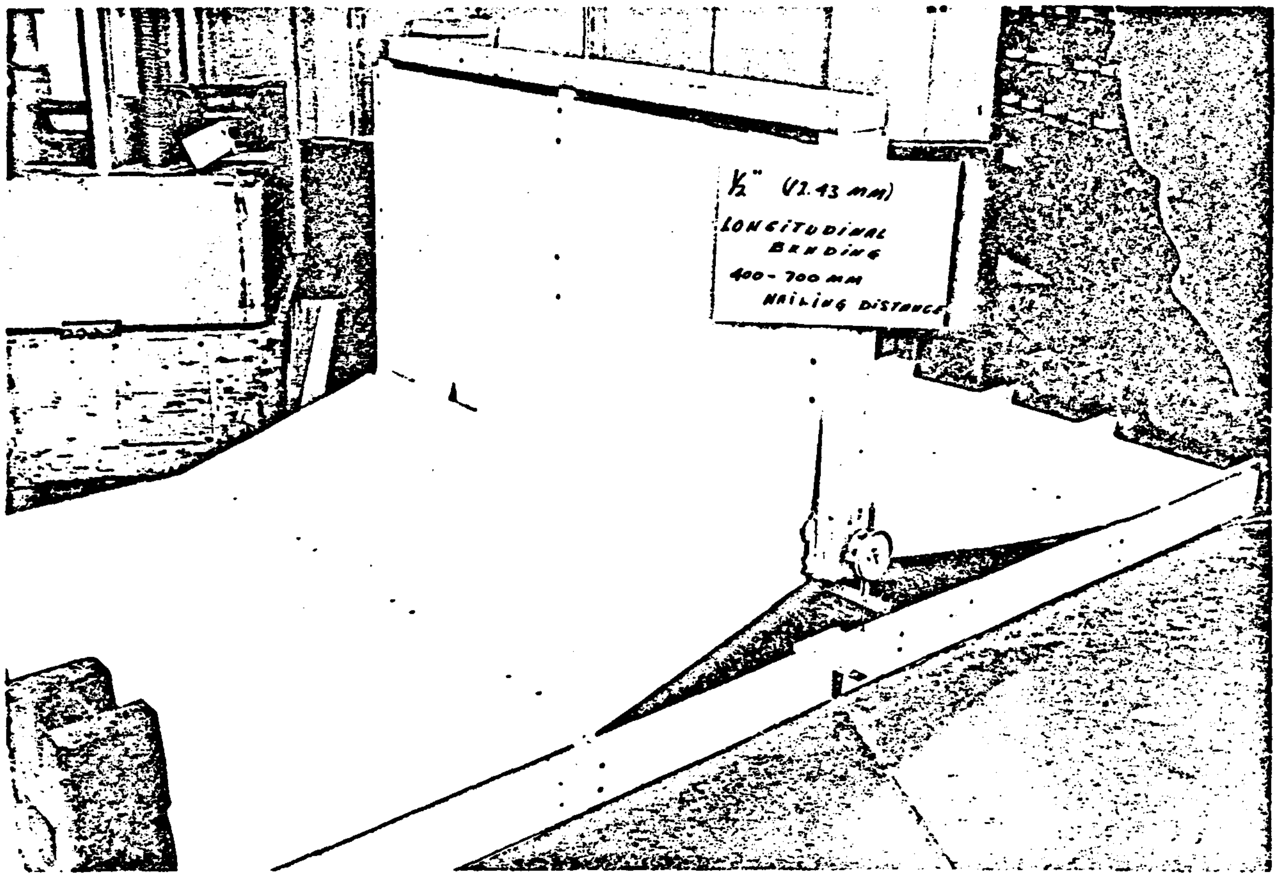


FIGURE 5: Photo of a Full-Sized T Specimen Made With 1/2-inch Gypsum Board Simulating a Partition Parallel to the Roof Trusses After Failure of the 400 mm Cantilever.

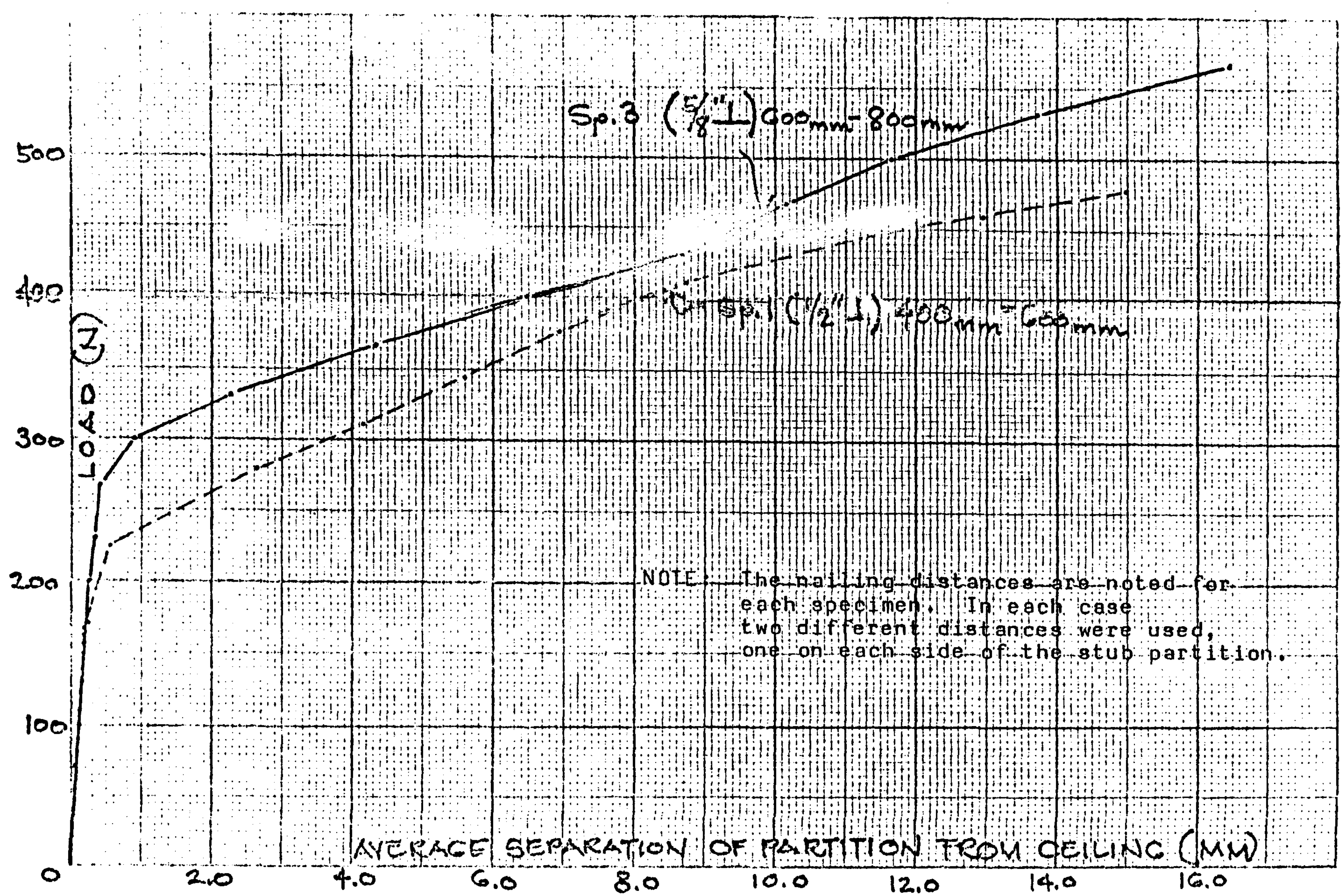


FIGURE 6: Plots of Load versus Separation for Two Full-sized T Specimens Simulating a Partition Perpendicular to the Roof Trusses.

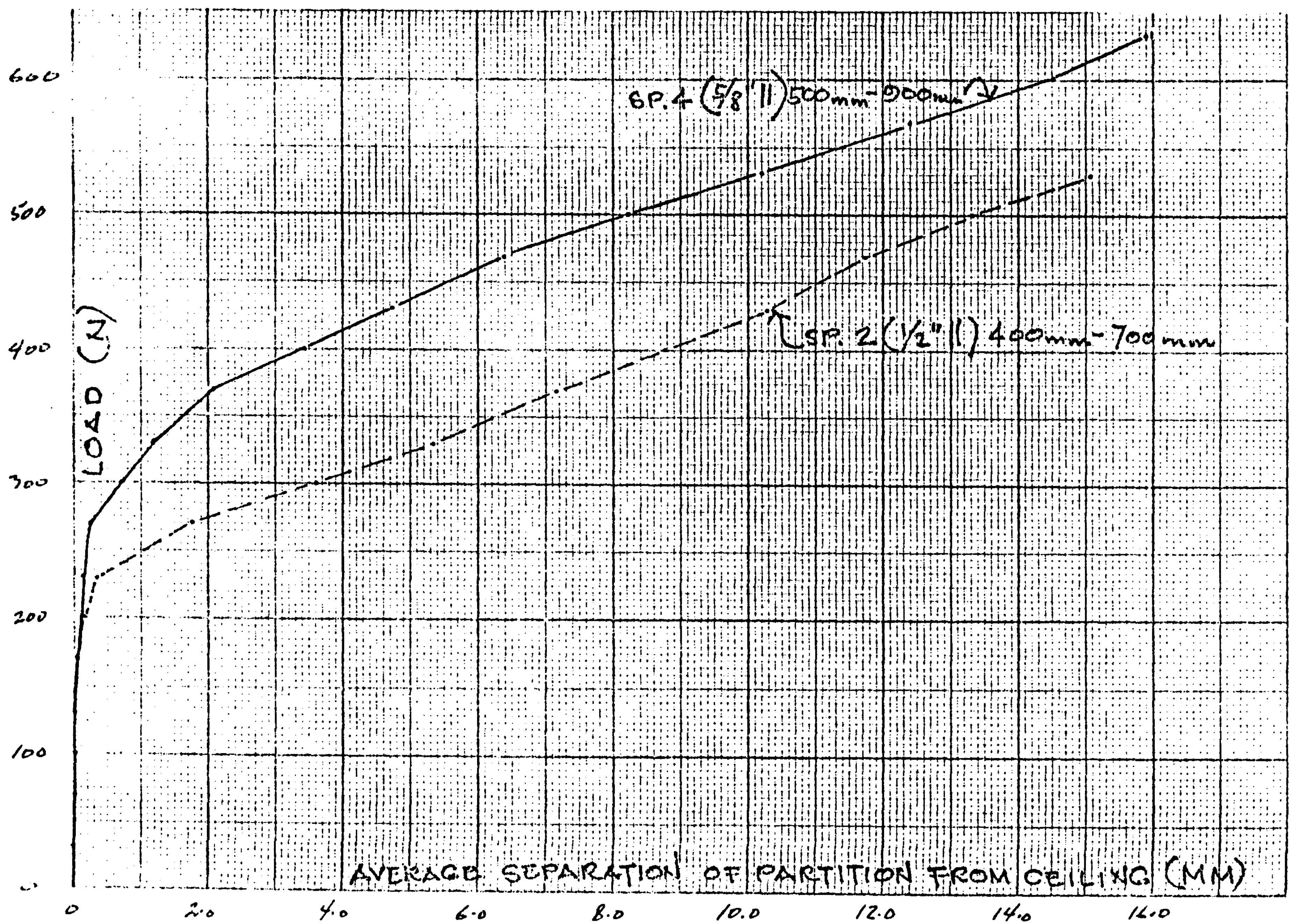


FIGURE 7: Plots of Load versus Separation for Two Full-sized T Specimens Simulating a Partition Parallel to the Roof Trusses.

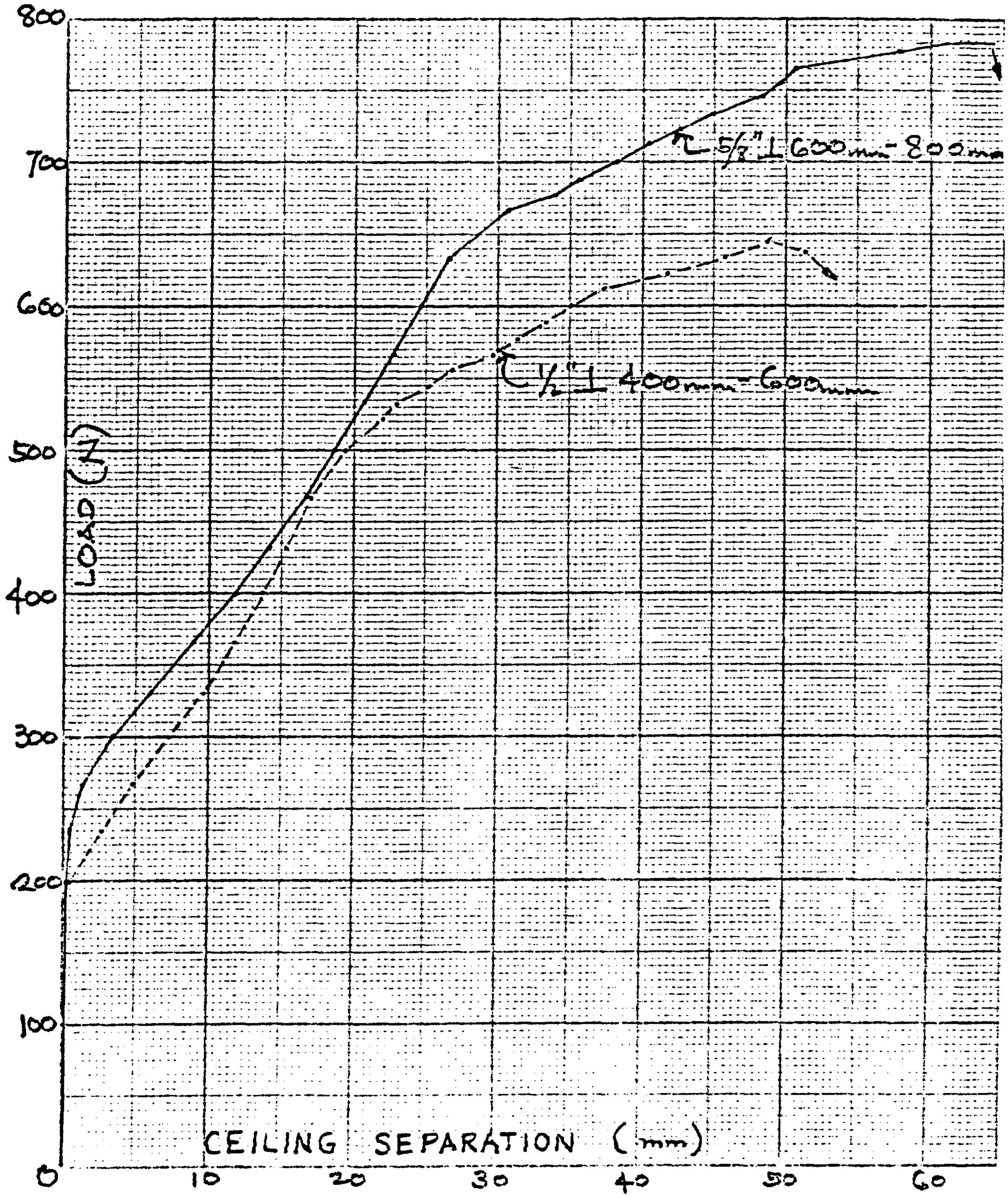


FIGURE 8: Plots of Load to Failure versus Ceiling Separation for Two Full-Sized T Specimens Simulating Partitions Perpendicular to the Roof Trusses.

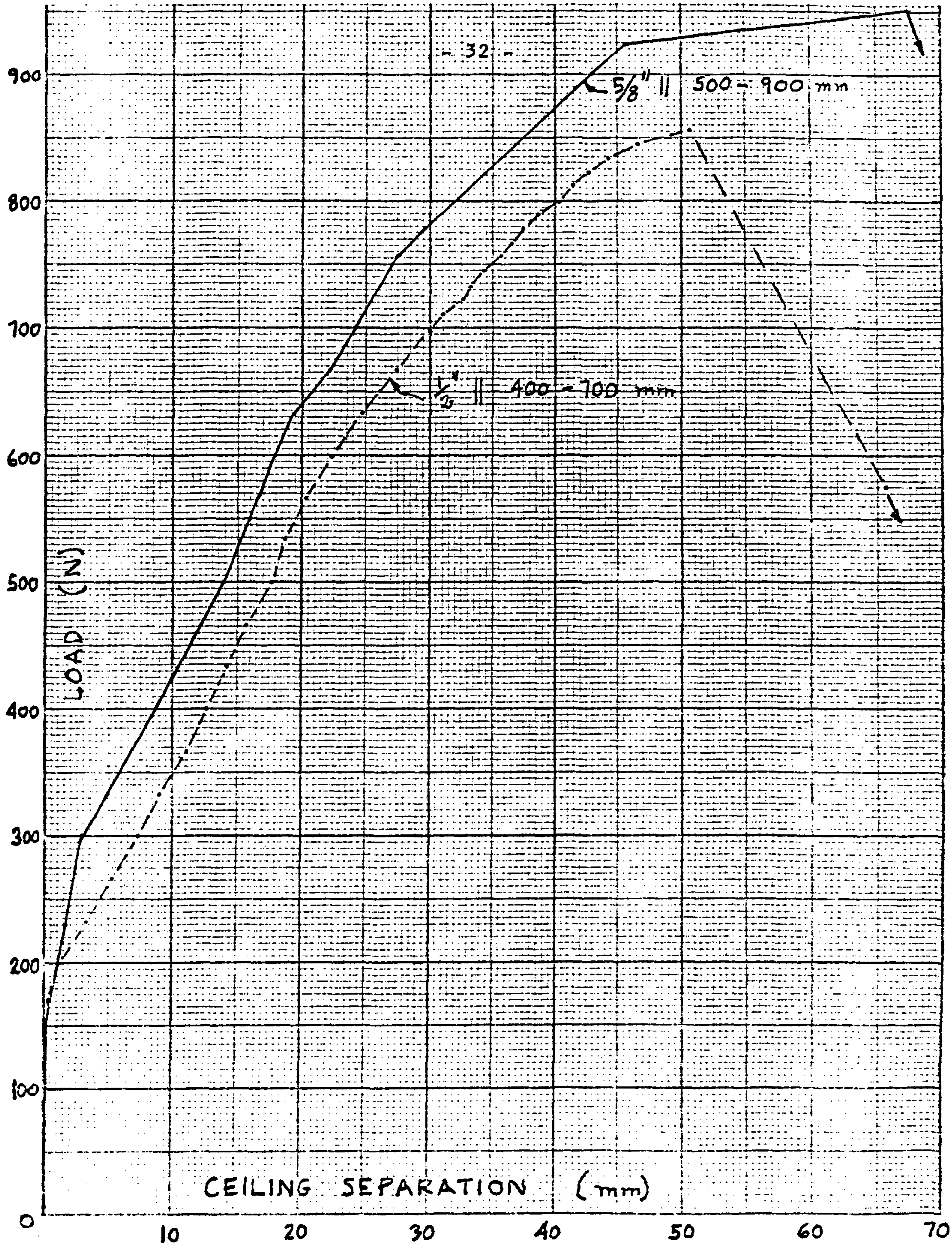


FIGURE 9: Plots of Load to Failure versus Ceiling Separation for Two Full-Sized T Specimens Simulating Partitions Parallel to the Roof Trusses.

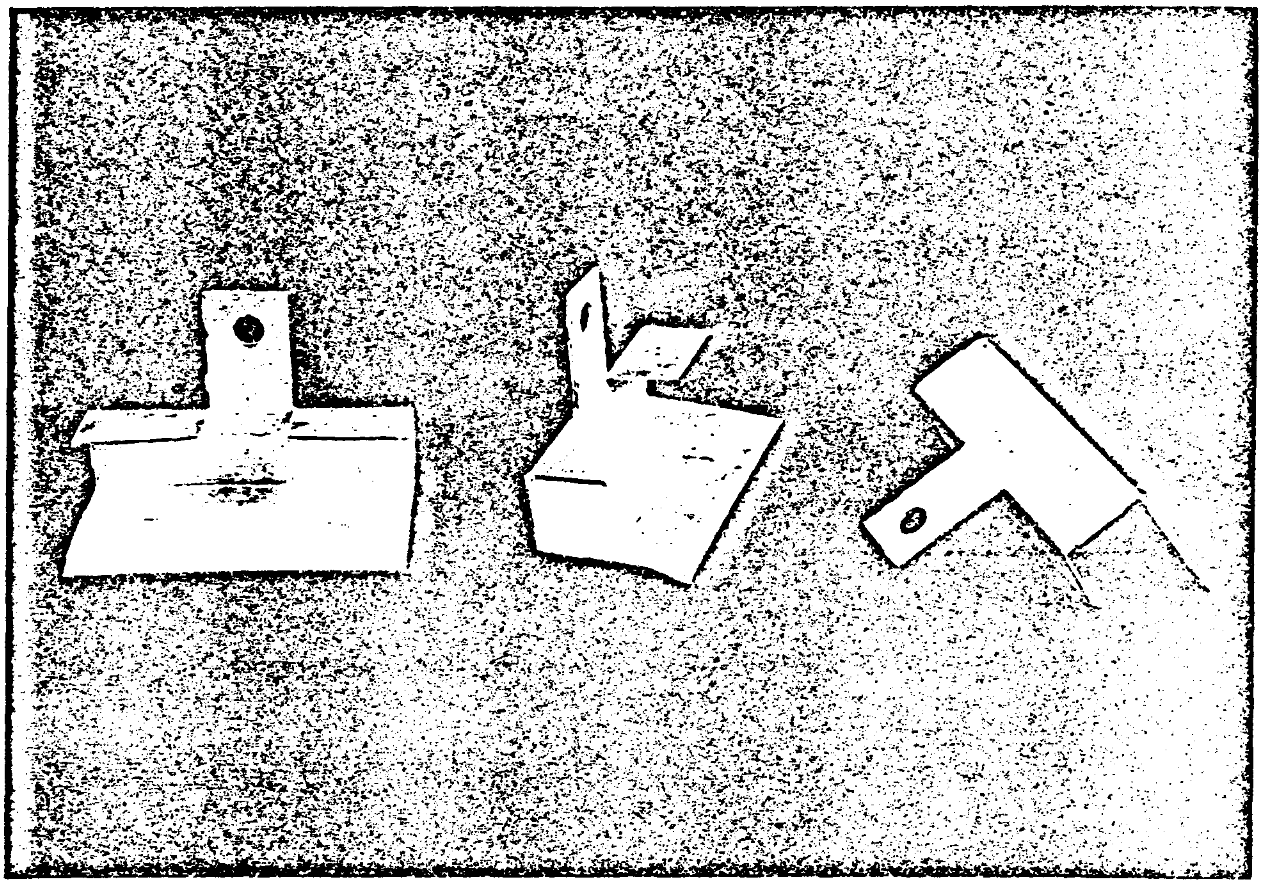


FIGURE 10: Framing Clips Used to Attach the Edge of the Ceiling Gypsum Board to the Partitions.

Table 1: Nailing Distances for Cantilever Bending Test[1]

distance from clip to first nail mm(inches)	Specimen axis[2] perpendicular to axis of sheet	Specimen axis[2] parallel to axis of sheet
300 (11.8)	A1	B1
400 (15.8)	A2	-
500 (19.7)	A3	B2
600 (23.6)	A4	-
700 (27.6)	-	B3
900 (35.4)	-	B4

[1] Nailing distances are given for each specimen. The same nailing distances were used for 1/2-inch and 5/8-inch gypsum board.

[2] See Figure 1 for cutting pattern

Table 2: Summary of Test Results for Cantilever Bending Tests of 1/2 inch Gypsum Boards

Specimen designation	Thickness mm	Clip distance from nearest nail mm	Maximum load per unit width N/mm	Maximum displacement at failure mm	EI per unit width $\times 10^6$ Nmm^2/mm	Failure[1] mode
A-1	12.61	300	0.176	31	0.101	Tensile break
A-2	12.62	400	0.139	47	0.155	Tensile break and nail pull-through
A-3	12.57	500	0.130	68	0.164	Tensile break
A-4	12.60	600	0.115	84	0.187	Tensile break
B-1	12.59	300	0.307	29	0.116	Nail pull-through only
B-2	12.56	500	0.226	79	0.185	Nail pull-through only
B-3	12.54	700	0.179	98	0.285	Tensile break
B-4	12.54	900	0.118	164	0.311	Tensile break

1 Tensile break refers to a failure of the tension face which in these tests, was the back paper facing.

Table 3: Summary of Test Results for Cantilever Bending Tests of 5/8-inch Gypsum Board.

Specimen designation	Average specimen thickness mm	Clip distance from nearest nail mm	Maximum load per unit width N/mm	Maximum displace-ment at failure mm	EI per unit width 10^6 Nmm^2/mm	Failure mode
A-1	16.08	300	0.312	34	0.221	Tensile break
A-2	15.93	400	0.264	61	0.303	Tensile break
A-3	15.90	500	0.225	64	0.398	Tensile break
A-4	15.92	600	0.189	100	0.424	Tensile break
B-1	15.94	300	0.512	34	0.244	Pull-through only
B-2	15.94	500	0.374	58	0.526	Tensile break
B-3	15.81	700	0.284	102	0.574	Tensile break
B-4	15.82	900	0.243	156	0.626	Tensile break

[1] Tensile break refers to a failure of the tension face which in these tests , was the back paper facing

Table 4: Summary of Test Results for Standard Bending Test of 1/2-inch Gypsum Board.[1]

Specimen[2] mark	Average thickness mm	Maximum load per unit width N/mm	EI per unit width $\times 10^6$ N mm^2/mm
A-1-1	12.58	0.66	0.230
A-2-1	12.57	0.67	0.232
A-3-1	12.61	0.72	0.211
A-4-1	12.61	0.71	0.245
A-5-1	12.60	0.70	0.217
A-6-1	12.56	0.69	0.175
A-7-2	12.57	0.66	0.243
A-8-2	12.60	0.66	0.193
A-9-2	12.55	0.72	0.259
A-10-2	12.62	0.71	0.209
Mean	12.59	0.69	0.221
B-1-2	12.62	1.84	0.317
B-2-2	12.61	1.85	0.335
B-3-2	12.58	1.80	0.351
B-4-2	12.59	1.99	0.345
Mean	12.60	1.90	0.337

[1] Specimen tested face down

[2] "A" designates bending transverse to sheet direction; "B" designates bending in the sheet direction. The second number in the code identifies the specimen number in a set while the third number designates the sheet number, i.e. either 1 or 2.

Table 5: Summary of Test Results for Standard Bending Test of 5/8-inch Gypsum Board[1].

Specimen[2]	Average thickness mm	Maximum load per unit width N/mm	EI per unit width $\times 10^6$ $N\ mm^2 / mm$
A-1-3	15.97	1.12	0.567
A-2-3	15.98	1.12	0.538
A-3-3	16.01	1.20	0.541
A-4-3	15.96	1.16	0.473
A-5-4	15.72	0.90	0.456
Mean	15.93	1.10	0.515
B-1-3	15.89	2.90	0.768
B-2-4	15.82	2.90	0.736
Mean	15.86	2.90	0.752

[1] Specimens tested face down

[2] A designates bending transverse to sheet direction; B designates bending in the sheet direction. The second number in the code identifies the specimen number in a set, while the third number designates the sheet number, i.e., either 3 or 4.

APPENDIX A

Design of Nailing Distances to Permit Flexibility at Ceiling/Partition Connection

A: 12.6 mm Gypsum Board Properties

The following data have been extracted from Table 2 for cantilever bending tests of 1/2-inch gypsum board:

Average Maximum Moment at failure (weak direction):

M_2 = 60.6 Nmm/mm

Average maximum moment at failure (strong direction), ignoring specimens B-1 and B-2 which failed as a result of nail pull-through:

M_1 = 115.8 Nmm/mm

Average EI product (weak direction):

$EI_2 = 0.152 \times 10^6$ Nmm²/mm

Average EI product (strong direction) including specimens B-1 and B-2:

$EI_1 = 0.224 \times 10^6$ Nmm²/mm

Nail pull-through occurred in tests of two specimens at reactions of 0.307 and 0.236 N/mm which are equivalent to total forces of 187 N and 140 N per pair of nails.

Assume for illustrative purposes that the above means represent the average for the total population and that a coefficient of variation of 0.15 is a reasonable estimate of the population variability. An estimate for the lower 5 percent exclusion limits for the resisting moments m_1 and m_2 are:

$m_2 = M_2 - 0.15 M_2 k$

$= 60.6\ (1 - 0.15 \times 1.645) = 45.6$ Nm/mm

$m_1 = M_1 - 0.15\ M_1 k$

$= 115.8\ (1 - 0.15 \times 1.645) = 87.2$ Nm/mm

The EI products determined by means of the standard bending test in accordance with CSA A82.20.3-M1977 were higher than those values found using the cantilever test. Several reasons have already been advanced in the text to explain this discrepency. One of these concerned the difference in the rate of strain employed in the two tests. In applying either test result to an event that takes several weeks as compared to one that takes from 5 to 15 minutes we must admit that a significantly lower effective EI will pertain but one that is not known. In design for flexibility one should use a basic value that represents an upper exclusion limit. Since the effective EI will be lower, we will assume for the following calculations that some level of upper exclusion limit will have decreased to the mean of the short term cantilever test results.

B: Equations for Bending Moments, Deflection and Nail Forces

The deflection of a cantilever with an end load is:

$$y = \frac{1}{3} \frac{PL^3}{EI}$$

where: y = deflection

P = end load

L = span

EI = the product of modulus of elasticity and effective moment of inertia.

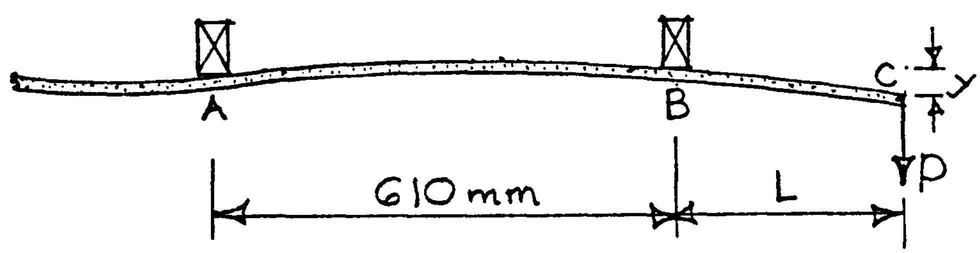
Given that the applied moment M = PL,

$$y = \frac{ML^2}{3EI}$$

Rearranging terms,

$$M = \frac{3EIy}{L^2} \quad . \qquad (1)$$

Equation (1) may be used for calculating the moment produced when the cantilever tip deflects a distance y when the partition is perpendicular to the trusses. A different situation applies when the partition is parallel to the trusses as shown in the following sketch.



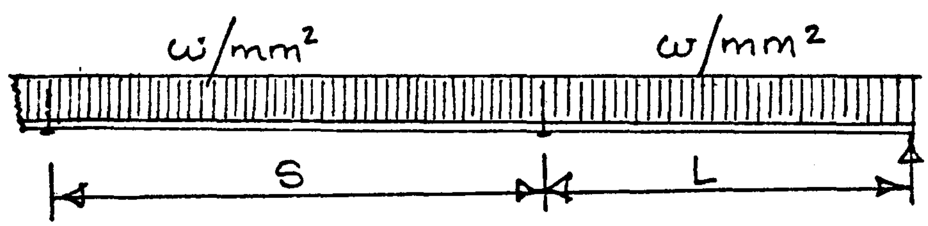
Conservatively, we will assume that there is full fixity at location A and that there is a pivot at B. The deflection at C is given by:

$$y = \frac{PL^2}{EI}\left(\frac{L}{3} + \frac{610}{4}\right)$$

$$\text{or } y = \frac{M_b L}{EI}\left(\frac{L}{3} + \frac{610}{4}\right)$$

$$\text{and } M_b = \frac{y\,EI}{L\left(\frac{L}{3} + \frac{610}{4}\right)} \qquad (2)$$

An estimate of the negative moment at the first line of nails from the partition caused by dead loading of insulation and the weight of the gypsum board is required. A simplified approach will be taken assuming that the spans on either side of the first line of nails do not have end moments, i.e., that there is continuity only at the first line of nails.



For this assumption, and from the Theorem of Three Moments, the moment at the central support is

$$M = \frac{w\,(S^3 + L^3)}{8\,(S + L)} \qquad (3)$$

The value S will be taken as 300 mm when partitions are perpendicular to the trusses and 610 mm when they are parallel to the trusses.

To estimate the weight of insulation and weight of gypsum board required to be borne by the first row of nails away from the partition, it will be assumed that the force required is proportional to the contributary area defined by the midpoints of the supporting elements. Plate action and continuity will be ignored in this estimate. The range of densities for cellulose fill insulation is from 22.1 to 40.7 kg/m^3 with an overall mean of 33.5 kg/m^3 and a standard deviation of means of 4.26 kg/m^3 (6). The upper 95% exclusion limit is 40.5 kg/m^3. Assuming a maximum insulation depth of 300 mm, the uniform insulation load is calculated to be 12.15 kg/m^2 or a force of 119.2 N/m^2 The weight of 1/2-inch gypsum board will be taken as 8.3 kg/m^2 (81.4 N/m^2). The total uniform load is thus approximately 200 N/m^2.

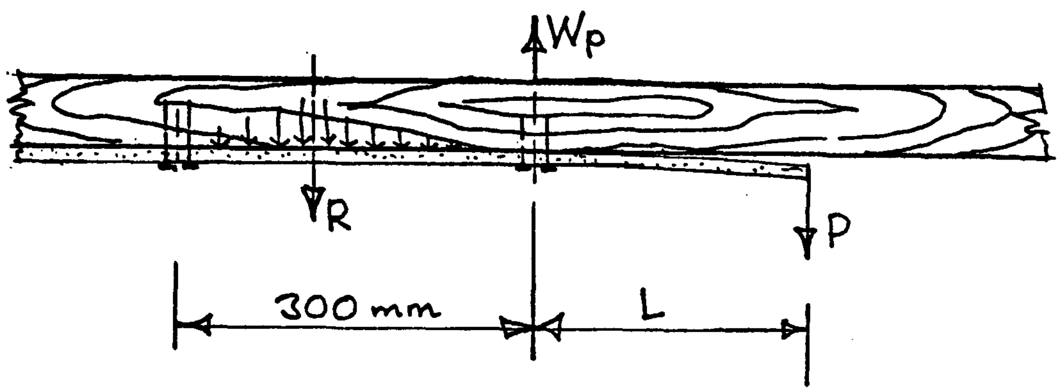
The dead load on the fasteners for partitions perpendicular to trusses spaced at 610 mm is thus

$$Wd = \frac{610\ (\frac{300 + L}{2})}{10^6} \times 200 \quad \text{N/pair of nails} \qquad (4)$$

while for partitions parallel to the trusses the fastener load due to dead loading is

$$Wd = \frac{300\ (\frac{610 + L}{2})}{10^6} \times 200 \quad \text{N/pair of nails.} \qquad (5)$$

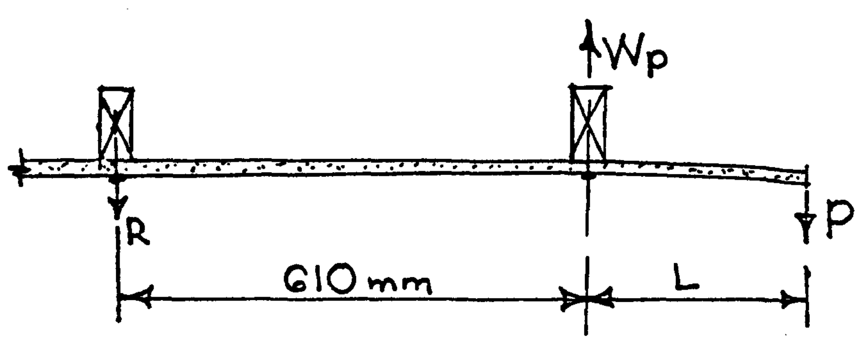
Additional nail loading will occur as a result of separation. The forces actually resisted depend on the manner that the gypsum board and truss chord interact; the forces depend on assumptions about the location of resisting forces. For example, in the sketch below the location of the force R is critical to the withdrawal force experienced by the fasteners. Creep of the gypsum board in bending and local deformations around the nails change the deflected shape of the gypsum board and alter the location of R.



For these calculations, we will assume that R is located 200 mm from W. The value of W in terms of P is therefore

$$Wp = (P + \frac{LP}{200})\ 610\ N \tag{6}$$

Less uncertainty exists about the location of R for the case of partitions located parallel to the trusses.



$$Wp = (P + \frac{LP}{610})\ 300\ N \tag{7}$$

The total fastener withdrawal force is the sum of Wp and Wd.

Equation (5) now allows us to calculate the actual pull-through force causing failure of cantilever specimens B-1 and B-2. These values were found to be 467 and 483 N/pair of nails. A third specimen which failed by nail pull-through which is not reported in Table 2 because it had been fabricated with an incorrect cantilever span gave a maximum pull-through force of 510 N. Assuming a coefficient of variation of 15 percent, an estimated lower 5 percent exclusion value based on the mean of the above tests is 367 N/pair of nails. We must stress that these assumptions and the end result are highly problematical. However, from necessity some estimate is required. It may be added that even if pull-through resistances were available as obtained by the method used in CSA A82.20.3-M77 these will not be of use because of the manner used in preparing the specimens. The test procedure is designed primarily for quality control purposes, and not for the purpose of providing design values for as-constructed attachments.

C: <u>Calculations for 1/2-inch Gypsum Board</u>

Summary of Properties:

$EI_1 = 0.224 \times 10^6$ Nmm²/mm

$EI_2 = 0.152 \times 10^6$ Nmm²/mm

m_1 = 87.2 Nmm/mm

m_2 = 45.6 Nmm/mm

nail pull-through = 367 N/pair of nails

A range of cantilever spans were studied. For each span and for a design separation of 15mm, the bending moment caused by separation was calculated, either by equation (1) or (2) depending on whether the partition lay across or along the roof trusses. The maximum moments introduced by a dead loading of 200 N/m^2 were calculated using equation (3). The sum of bending moments produced by separation and dead loads was obtained and divided into the appropriate lower 5 percent exclusion limit to give a "safety factor" against failure in bending. In a similar manner, the force applied to pairs of fasteners (or individually to screws) caused by separation was calculated by equation (6) or (7). The force on the nails caused by dead loads was obtained from equation (4) or (5). The sum of the two forces divided by 367 N gave the "safety factor" against failure by nail pull-through. The detailed calculations are summarized in Table A-1 and plots of "safety factors" for moments and nail pull-through *versus* the cantilever span are given in Figure A-1.

Table A-1: Calculation of Safety Factors for Various Cantilever Spans for 1/2-inch Gypsum Board at a Design Deflection of 15 mm.

	Bending Moment[1]					Nail Pull-Through Force			
Cantilever Span (mm)	Separation (Nmm/mm)	Dead Load (Nmm/mm)	Total (Nmm/mm)	Moment[1,2] Safety Factor	Cantilever Tip Force (Separation) (M/L) (N/mm)	Dead Load (N)	Separation (N)	Total (N)	Pull-Through[2] Safety Factor
Partition Perpendicular to Trusses									
300	76.00	2.25	78.25	0.58	0.253	36.6	385.8	422.4	0.87
400	42.75	3.25	46.00	0.99	0.107	42.7	195.8	238.5	1.54
500	27.36	4.75	32.11	1.42	0.055	48.8	117.4	166.2	2.21
600	19.00	6.75	25.75	1.77	0.032	54.9	78.1	133.0	2.76
700	13.96	9.25	23.21	1.96	0.020	61.0	54.9	115.9	3.17
Partition Parallel to Trusses									
300	44.36	6.98	51.34	1.70	0.148	27.3	66.2	93.5	3.92
400	29.38	7.20	36.58	2.38	0.073	30.3	36.3	66.6	5.51
500	21.05	7.83	28.88	3.02	0.042	33.3	22.9	56.2	6.53
600	15.89	9.15	25.04	3.48	0.026	36.3	15.5	51.8	7.09
700	12.44	10.88	23.32	3.74	0.018	39.3	11.6	50.9	7.21

[1] Moments and the moment safety factor are for the first line of nails from the partition.

[2] Basis for moment safety factors are m_1 = 87.2 Nmm/mm and m_2 = 45.6 Nmm/mm, and P = 367 N for the nail pull-through safety factor.

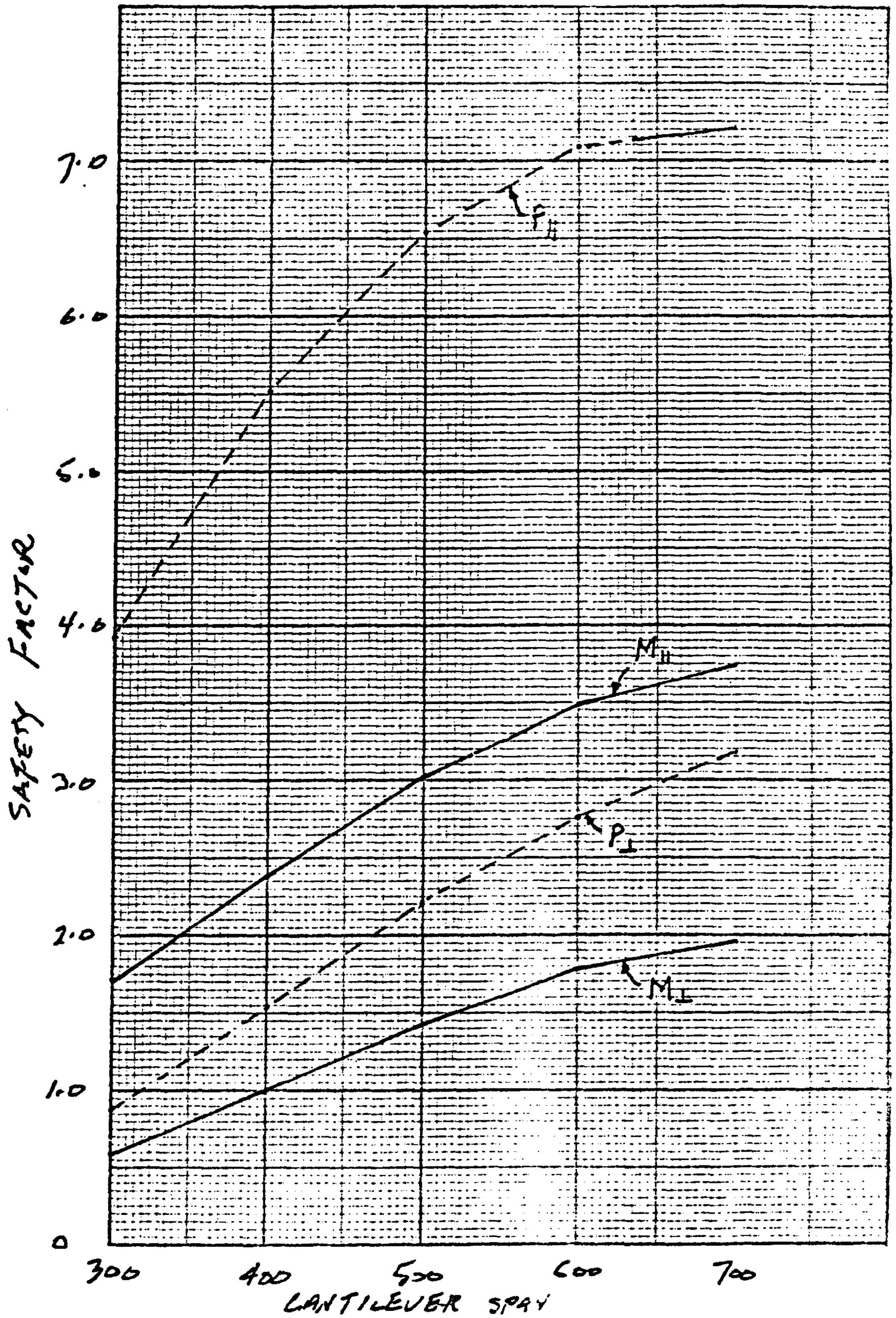


FIGURE A-1: Plot of Safety Factors Against Bending Failure or Nail Pull-through at a Ceiling/Partition Separation of 15 mm for 1/2-inch Gypsum Board

D: Selection of Nailing Distances for 1/2-inch Gypsum Board

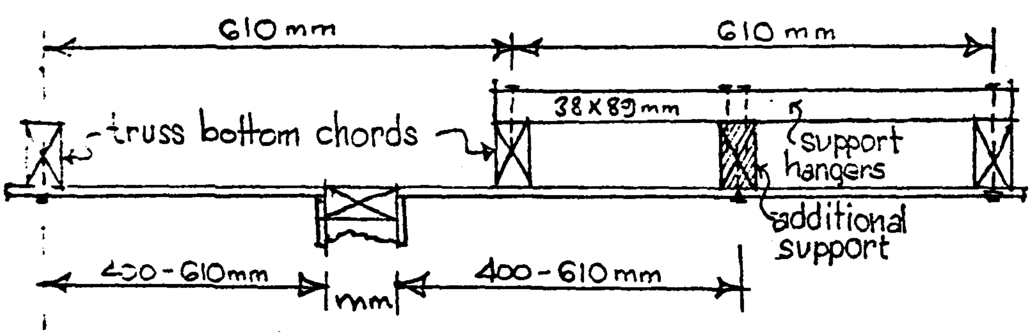
Examination of Figure A-1 shows that the moment capacity of the gypsum board controls the capacity of joints both when partitions are parallel to and perpendicular to the roof trusses. The reason that large safety factors against nail pull-through are available for the case of partitions parallel to trusses is that the nails are spaced comparatively closely and more than adequate capacity is available.

Another point to consider is that for a cantilever of 400 mm and the partition parallel-to-trusses case, a "safety factor"of only about 1.0 was calculated. Yet, the full-sized joints performed significantly better than this. One reason for this is that the calculations in this Appendix are an attempt to estimate what would happen if lower quality gypsum boards were encountered than were used in these tests. A second reason is that the calculations included estimates for the effect of dead loads. These were not adequately present in the full scale T Specimens since the primary purpose of the tests was to observe the behaviour of the joints of the ceiling/partition junction.

Present recommendations for "floating corners" by various gypsum board manufacturers is that a distance of 12 inches (304.8 mm) be used for minimizing cracking at corners. This would not appear to provide sufficient flexibility for the larger separations that are produced by truss uplift. Some builders are presently using an 18-inch (457 mm) set back based on practises being suggested by the Truss Plate Institute in the United States. This would provide a safety factor greater than 1.0, but so would a nailing distance of 500 or 600 mm.

In the full scale joint tests the longer cantilevers survived very well and were able to absorb very large separations. Although the "safety factors" in Figure A-1 show that even spans over 700 mm would be "safe", one must consider other performance characteristics that have not been evaluated here, namely creep under dead load leading to sag. The plots suggest that a 457 mm (18 inches) span gives a safety factor greater than 1.0, and a longer cantilever can probably be tolerated. The full scale tests showed that peeling of the joint tape began at about 27 mm for the 500 and 600 mmm cantilevers and at about 20 mm for the 400 mm cantilever. All things considered, a minimum cantilever span of 457 mm (18 inches) will be recommended. An interesting and potentially useful concomitant interaction is that between the EI product and maximum moment resistance. A board with a lower EI product may also have a lower bending strength. If so, a larger deflection can be tolerated without increasing the moment produced.

With regard to the minimum spacing required for the case of partitions parallel to the trusses there is no problem when the partition falls directly under a truss. The cantilever spans are approximately 565 mm which provide a very adequate margin on both bending moment and nail pull-through. On the basis of the full scale tests, a large reserve for potential separation is available. The problem occurs when the partition is too close to a truss location to allow flexibility. From the Figure A-1 it is seen that adequate moment and pull-through capability can be had with a 300 mm cantilever span at a design separation of 15 mm. On the basis of the observations of the performance of full-sized T specimens we caution that horizontal motion of the cantilever tip will likely lead to much earlier joint tape peeling. Noting that there was only a 1.20 reserve on joint peeling for a 400 mm span it would seem prudent to maintain at least this reserve. Our recommendations are that when the face of a partition is less than about 400 mm (15.75 inches) from the truss, nailing to it should be avoided. The unsupported span becomes 610 + 400 = 1010 mm which is far too large from the point of view of sagging. Instead, an additional roof rafter will have to be introduced so that the longer cantilever span does not lead to problems with sagging. The data in this report does not provide us with guidance on this subject. The



plots in Figure A-1 do suggest that the safety factor against nail pull-through or bending failure at the first line of nails would be quite adequate. But other studies and data will have to be studied or experiments will have to be done to advise on the maximum span tolerable from the point of view of sagging.